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Life Table and Predation Capacity of *Phytoseiulus persimilis* Athias-Henriot (Acari: Phytoseiidae) Feeding on *Tetranychus urticae* Koch (Acari: Tetranychidae) on Rose

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ABSTRACT

The life history and predation rate were determined for all stages of female and male of *Phytoseiulus persimilis* Athias-Henriot fed on the eggs of *Tetranychus urticae* Koch - as the preferred prey-stage - on rose (cv 'blarodje') leaf discs under laboratory conditions at 25±1°C, 75±5% RH, and 16 L: 8 D hour photoperiod. According to the age-stage, two-sex life table model, the intrinsic rate of increase (r), finite rate of increase (λ), net Reproductive rate (R_0), Gross Reproductive Rate (GRR), and mean generation Time (T) were 0.296 d^{-1}, 1.345 d^{-1}, 33.48 offspring, 53.87 offspring and 11.83 d, respectively. Moreover, average number of *T. urticae* eggs consumed by different stages/sexes of *P. persimilis* was calculated based on the age-stage, two-sex life table model and indicated that the consumption rates increased from nymph to adult in both sexes. Also, our results showed that females consumed prey eggs 11 times more than males. The net predation rate (C_0) and transformation rate from prey population to predator offspring (Q_p) were 363.54 mite eggs and 10.86, respectively. The results showed that *P. persimilis* can successfully survive and reproduce on *T. urticae* eggs on rose.

Keywords: Consumption rate, Intrinsic rate of increase, Life history, Predatory mite, Two-spotted spider mite.

INTRODUCTION

Tetranychid mites are destructive and widespread pests on many commercial crops. Roses in commercial greenhouses commonly suffer from attacks by *Tetranychus urticae* Koch, the most serious pests of tetranychid mites, which can cause both reduction in plant growth and aesthetic injury to the rose flowers and leaves (Mercurio, 2007). There is a low tolerance to mite damage in ornamental crops because the whole plant is marketed (Skirvin and Fenlon, 2003; Mercurio, 2007). Furthermore, the extensive pesticides application by growers has become a common practice. However, due to associated problems of excessive use of chemicals such as resistance to pesticide and pesticide residues, there is much emphasis on using environmentally safe measures such as biological control (Naher *et al*., 2005; Abad-Moyano *et al*., 2009). Predatory mites from phytoseiid family are important natural enemies of phytophagous mites on different crops and known as effective biocontrol agents for these pests (Rasmy *et al*., 1991; Krips *et al*., 1999; DeCourcy Williams *et al*., 2004; McMurtry *et al*., 2013). Although, phytoseiid mites are not voracious compared to insect predators; however, their feeding preference to phytophagous mites, short generation time, high survival rate and better ability to mass production than most insects, make them useful biological control agents of spider mites in integrated pest management programs (Abad-Moyano *et al*., 2009).

Phytoseiulus persimilis Athias-Henriot is known as a specialized predator of tetranychid

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mites, especially *Tetranychus* species, which is widely used with success in protected crops (Sabelis, 1985b; Khalequzzaman *et al*., 2007; McMurtry *et al*., 2013). Life table of *P. persimilis* on *T. urticae* has been studied on several crops (Kazak *et al*., 1989; DeCourcy Williams *et al*., 2004; Escudero and Ferragut, 2005; Abad-Moyano *et al*., 2009; Mohamed and Omar, 2011), but very little is known about its life history and predation capacity on rose. The present study was conducted to evaluate development, life table parameters and predation rate of *P. persimilis* (in both females and males) feeding on *T. urticae* eggs - as the preferred prey-stage (Moghadasi *et al*., 2013) - on rose in the laboratory conditions.

MATERIALS AND METHODS

Plant Source

The rose plants (*Rosa hybrida* cv. 'blarodje' (Rosaceae)) used in this study, were grown in beds under commercial conditions (Cocopeat: Perlit; 60%: 40%) in a greenhouse. The roses were pruned and planted in large plastic pots (top 25 cm diameter, 40 cm depth and bottom 20 cm diameter) at 25±2°C, 65±10% relative humidity and 16:8 (L: D) hour photoperiod.

Prey Source

Tetranychus urticae were originally collected from infested lima bean leaves in acarology laboratory at the Department of Plant Protection, College of Agriculture, University of Tehran, Karaj, Iran. These mites were reared on rose leaves placed underside up on water-saturated cotton wool in transparent plastic containers (20×10×4 cm). Water keeps the leaves fresh and prevents mites from escaping. When mite densities on leaves reached a high level, some of these leaves were cut into small pieces and were used on infested fresh rose leaves to establish a colony of *T. urticae* on rose. Other infested leaves were transferred to the predator rearing units as a food source. The rearing containers were kept in a growth chamber at 24±2°C, 60±5% RH, and 16 L: 8 D hour photoperiod, for three months before the beginning of experiments.

Predator Source

Phytoseiulus persimilis culture was initially obtained from laboratory stock culture reared at the laboratory. The predator rearing unit included a plate of green hard plastic on a water-saturated sponge in a container (26×16×7 cm). The borders of sponge were surrounded with moistened tissue papers to provide water supply for phytoeiids and to prevent them from escaping (Overmeer, 1985). Every two days, *T. urticae*-infested rose leaves were supplied as food. This culture was started three months before the beginning of experiments. The rearing unit was maintained at 25±1°C, 75±5% RH and 16 L: 8 D in a growth chamber.

Experimental Unit

The experimental units consisted of rose leaf discs. Four pieces of green hard plastic (4×1 cm) were placed on four margins of a water-saturated sponge (4×4×1 cm) in a 6 cm diameter Petri dish. A rose leaf square (3×3 cm) was placed upside down on the center of this unit. The borders of the unit were surrounded with wet tissue paper strips (0.5 cm width) as barriers. In such experimental unit designs, leaves are easily replaceable with fresh ones without need to rearrange the experimental units in each leaf replacement process. Experimental units were held at laboratory conditions similar to predator rearing units.

Life Table Study

Mite eggs laid during 16 hours were used for construction of the life table. 70 eggs were obtained randomly and transferred

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individually into experimental units. After the emergence of protonymphs, *T. urticae* eggs –as the preferred prey-stage (Moghadasi *et al*., 2013)– were supplied as food. Preliminary experiments showed that different numbers of *T. urticae* eggs should be supplied to different stages of *P. persimilis*: 30 eggs for protonymph, 30 eggs for deutonymph and 75 eggs for a pair of male and female. Observations were made every 12 hrs and developmental duration of egg, larva, protonymph, and deutonymph were recorded for both female and male. After adults' emergence, females and males were paired and monitored daily to record death and reproduction. To determine the sex ratio of *P. persimilis* offspring, every four days the laid eggs by all females were collected and maintained until adult stage.

Predation Rate

To provide prey eggs for predation rate study, *T. urticae* adult females were placed in each experimental unit to lay eggs, daily. After each day, females were removed without removing their web and eggs were decreased to the required density. As described before, different numbers of *T. urticae* eggs were supplied to different stages of *P. persimilis*. Experimental units were monitored every day and the number of consumed prey was recorded and the pre-designated density of prey eggs was provided to different stages of *P. persimilis*. After adult emergence, and pairing females and males, each pair was given 75 eggs and the number of consumed eggs was recorded until the death of predators. To separate the predation rate of males from that of females, the consumption rate of 20 single-males was recorded under similar conditions (Farhadi *et al*., 2011). To determine the female daily consumption rate, the average male consumption was subtracted from consumption of pairs.

Life Table Analysis

Raw data of developmental time, survivorship, longevity and fecundity of all replicates were analyzed. Following Chi and Liu (1985), age-stage specific survival rate (s_{xj}) (where x is age and j is stage), age specific survival rate (l_x), age-stage specific fecundity (f_{xj}), age-specific fecundity (m_x) and population parameters including: r (the intrinsic rate of increase), λ (the finite rate of increase), R_0 (the net Reproductive rate), *GRR* (the Gross Reproductive Rate), T (mean generation Time) were estimated based on age-stage and two-sex life table (Chi and Liu, 1985; Chi, 1988) using TWOSEX-MS Chart software (Chi, 2014a). The age-specific survival rate (l_x) and the age-specific fecundity (m_x) for both female and male are estimated as follows (Chi and Liu, 1985):

$$l_x = \sum_{j=1}^{\beta} s_{xj} \quad (1)$$

and

$$m_x = \frac{\sum_{j=1}^{\beta} s_{xj} f_{xj}}{\sum_{j=1}^{\beta} s_{xj}} \quad (2)$$

Where, β is the number of stages. Intrinsic rate of increase (r) was estimated using the iterative bisection method and Euler-Lotka Equation (x started from 0) (Goodman, 1982):

$$\sum_{x=0}^{\infty} e^{-r(x+1)} l_x m_x = 1 \quad (3)$$

The other life table parameters were estimated as follows:

$$\lambda = e^r \quad (4)$$

$$GRR = \sum m_x \quad (5)$$

$$R_0 = \sum_{x=0}^{\infty} l_x m_x \quad (6)$$

$$T = \frac{ln(R_0)}{r} \quad (7)$$

We used the Bootstrap method (Meyer *et al*., 1986; Huang and Chi, 2012) to calculate means and Standard Errors (SE) of the parameters of life table.

Predation Rate Analysis

Raw data of daily predation of all individuals were analyzed to calculate the predation rate according to Chi and Yang (2003) by CONSUME-MSChart software (Chi, 2014b). The age-specific predation rate (k_x) is the mean number of prey consumed by the predator at age x and could be estimated by the following formula (Chi and Yang, 2003):

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$$k_x = \frac{\sum_{j=1}^{\beta} s_{xj} c_{xj}}{\sum_{j=1}^{\beta} s_{xj}} \quad (8)$$

Where, β is the number of stages and c_{xj} is the age-stage specific consumption rate of individuals at age x and stage j. The age-specific net predation rate (q_x), takes the survival rate into consideration and is estimated as follows (Chi and Yang, 2003):

$$q_x = l_x k_x \quad (9)$$

The net predation rate (C_0), shows the mean number of prey consumed by a predator during its life span that was estimated as follows:

$$C_0 = \sum_{x=0}^{\infty} l_x k_x = \sum_{x=0}^{\infty} q_x \quad (10)$$

The ratio of the net predation rate to the net reproductive rate gives the transformation rate from prey population to predator offspring. Following Chi and Yang (2003), this ratio was defined as Q_p and estimated as follows:

$$Q_p = \frac{C_0}{R_0} \quad (11)$$

This rate represents the mean number of prey needed for a predator to produce an egg. Standard errors of predation parameters were also estimated based on the Bootstrap method.

RESULTS AND DISCUSSION

Developmental Periods

Pre-adult mortality of *P. persimilis* was 3 percent. Mean developmental times of each pre-adult stage and adult longevities of female and male as well as the female fecundity are presented in Table 1. The developmental period of all pre-adult stages was 4.32±0.05 days (n= 55). Females of *P. persimilis* lived an average of 21.38±1.26 days (n= 30), which was significantly longer (P< 0.001, Mann-Whitney U-test) than that of males (15.52±1.31 days, n= 25). The developmental durations for all stages in males and females in this study, were shorter than those reported by Mohamed and Omar (2011) on potato leaf disc. This difference may be due to different plant species that prey have reared on it. Nutritional value of various host plant species are involved in growth of both prey and predator (McMurtry *et al*., 2013; Sabelis, 1985c). Abad-Moyano *et al*. (2009) reported shorter developmental periods of *P. persimilis* (regardless of sex) than our results on Clementine leaf disc at 80±5% RH, possibly as a result of higher relative humidity than our study, since high humidity decreases the developmental durations in phytoseiid mites (Sabelis, 1985a; DeCourcy Williams *et al*., 2004).

Pre-oviposition period and total pre-oviposition period were recorded as 1.45±0.04 and 6.00 days (n= 30), respectively. The mean fecundity of females was 68.03±4.58 (n= 30) eggs. Our results indicated a higher fecundity of *P. persimilis* than that investigated by Kazak *et al*. (1989), Escudero and Ferragut (2005) and Mohamed and Omar (2011),

Table 1. Developmental times (day) of different stages, adult longevities, fecundity, adult preoviposition period and total preoviposition period of *Phytoseiulus persimilis* fed on *Tetranychus urticae* eggs at 25±1°C and 75±5% RH.

Statistics	N	Mean	SEM
Developmental time (d)			
Egg	61	1	0
Larva	61	1.08	0.02
Protonymph	59	1.1	0.04
Deutonymph	55	1.14	0.05
Total pre-adult	55	4.32	0.05
Adult longevity (d)			
Female	30	21.38	1.26
Male	25	15.52	1.31
Fecundity (F) (eggs female^{-1})	30	68.03	4.58
Adult Pre-Oviposition Period (APOP) (d)	30	1.45	0.04
Total Pre-Oviposition Period (TPOP) (d)	30	6	0

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possibly due to different plant species (as mentioned above) and experimental conditions.

The age-stage survival rate (s_{xj}) of *P. persimilis* is given in Figure 1. The curve demonstrates the probability that a newborn will survive to age *x* and stage *j*. The number of offspring produced by an individual *P. persimilis* of age *x* and stage *j* per day (age-stage specific fecundity rate) is shown in Figure 2. Because only females reproduce, there is only a single curve, f_{x5} that represents females in the fifth life stage. The age-specific survival rate (l_x), the age-specific fecundity (m_x) and the age-specific maternity (l_xm_x) of *P. persimilis* are also plotted in Figure 2.

Population Parameters

The population parameters, based on the Chi and Liu (1985), were calculated based on cohort data, including both sexes and

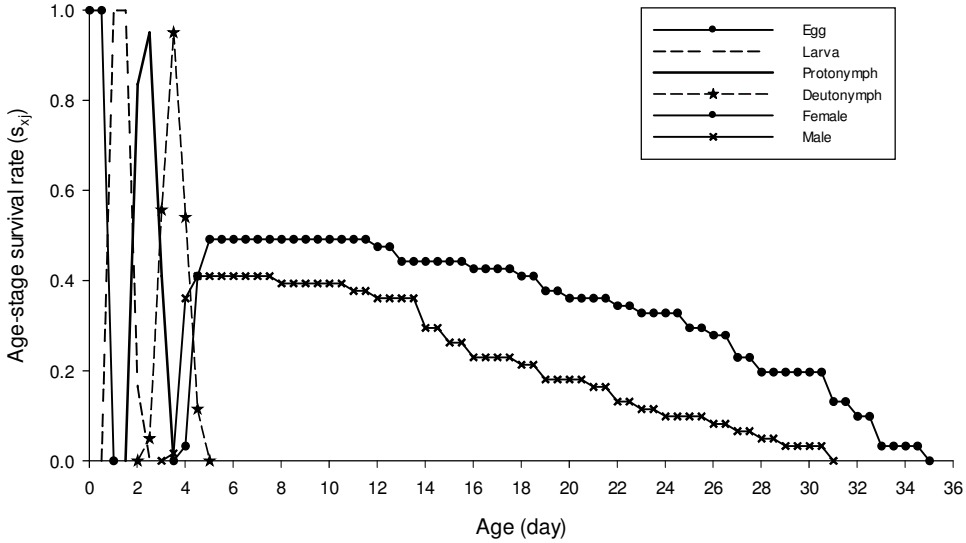

Figure 1. Age-stage survival rate (s_{xj}) of *Phytoseiulus persimilis* fed on *Tetranychus urticae* eggs at 25±1°C and 75±5% RH.

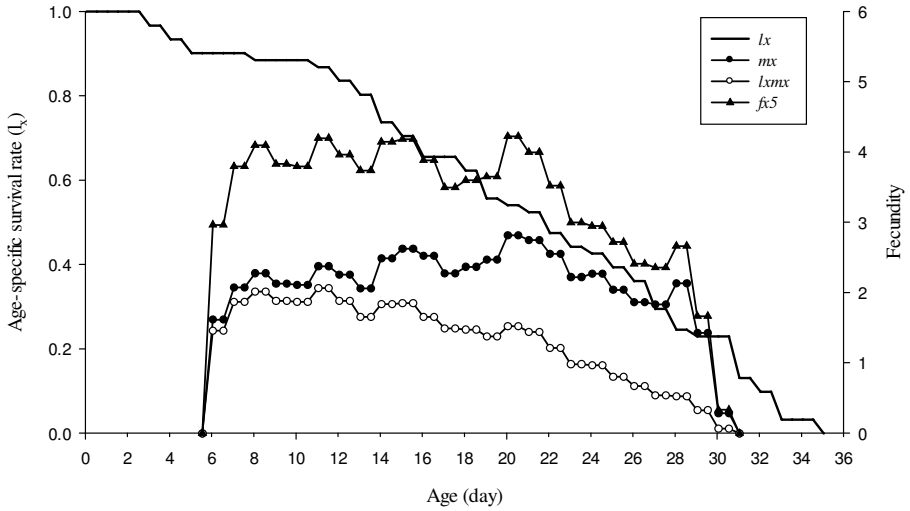

Figure 2. Age-specific survival rate (l_x), age-specific fecundity (m_x), age-specific maternity (l_xm_x) and age-stage specific fecundity (f_{x5}) of *Phytoseiulus persimilis* fed on *Tetranychus urticae* eggs at 25±1°C and 75±5% RH

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different developmental rates among individuals. Calculated parameters and their *SE* are shown in Table 2.

All of the *Phytoseiulus* species have a high potential for population increase (Sabelis, 1985c; Gotoh *et al*., 2004; McMurtry *et al*., 2013). However, the *r*-value can vary greatly due to the plant on which the prey feeds, prey species and stage, environmental conditions such as temperature and humidity as well as data analysis methods (Sabelis, 1985c; Gotoh *et al*., 2004).

According to Kazak *et al*. (1989) and Mohamed and Omar (2011), the R_0-values of *P. persimilis* were lower than our result. On the other hand, the *r*-value of *P. persimilis* in our study was lower than those reported by Kazak *et al*. (1989) and Abad-Moyano *et al*. (2009) and higher than those of Mohamed and Omar (2011). Gotoh *et al*. (2004) represented that a wide difference in *r*-value is sometimes found between populations of the same species.

As proven by Chi (1988), based on the two-sex life table, the relationship between female Fecundity (F) and net Reproductive rate (R_0) can be described by the following equation:

$$R_0 = F \times \frac{N_f}{N} \quad (12)$$

Where, N is the number of individuals used at the beginning of the study (here, 60 eggs) and N_f is the number of female adults that emerged from N. This equation also demonstrated that $N_f \times F = R_0 \times N$. In our results, $N_f \times F$= 2040.9 and $R_0 \times N$= 2041.06. This minor difference is due to rounding-off. This relationship indicates the obtainable accuracy in the age-stage and two-sex life table analysis.

Predation rate

The numbers of *T. urticae* eggs consumed by different stages/sexes of *P. persimilis* are shown in Table 3. It indicates that the consumption rates increase from nymph to adult in both sexes. The total mite eggs consumed by deutonymph are more than the protonymph in female and fewer than the protonymph in male. Females, because of their bigger body size and more energy requirement for egg production as well as the longer adult longevity, consumed prey

Table 2. Population parameters of *Phytoseiulus persimilis* fed on *Tetranychus urticae* eggs at 25±1°C and 75±5% RH.

Parameter[a]	Mean	SEM
r (d^{-1})	0.296	0.014
λ (d^{-1})	1.345	0.019
R_0 (Offspring/Individual)	33.48	4.93
GRR (Offspring)	53.87	6.27
T (d)	11.83	0.26

[a] r= Intrinsic rate of increase; λ= Finite rate of increase; R_0= Net Reproductive rate; *GRR*= Gross Reproductive Rate, T= Mean generation Time.

Table 3. Mean number of *Tetranychus urticae* eggs eaten by different stage/sex of *Phytoseiulus persimilis* at 25±1°C and 75±5% RH.[a]

Stage	Sex	
	Female (Mean±SE)	Male (Mean±SE)
Protonymph	5.57±0.46 a	7.28±0.56 b
Deutonymph	8.03±0.64 a	4.16±0.83 b
Pre-adult	13.6±0.48 a	11.44±1.17 a
Adult	665.4±41.34 a	60.16±5.56 b
All stages	679.03±41.45 a	71.6±5.33 b

[a] Means followed by the same letters within rows are not significantly different (P< 0.05, t-test).

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eggs 11 times more than males. The higher prey consumption in females of *P. persimilis* compared to males on *T. urticae* has been reported by Rasmy *et al*. (1991) on raspberry, Naher *et al*. (2005) on bean and Khalequzzaman *et al*. (2007) on eggplant, too.

Differences in physical and chemical characteristics of plants, especially trichome and hair density, as well as the spider mite webs could lead to differences in predation among phytoseiid mites (Sabelis, 1985b; McMurtry *et al*., 2013). Krips *et al*. (1999) investigated that the predation rate of *P. persimilis* females on three cultivars of Gerbera is affected by trichome density, particularly when prey density is low. Moreover, the differences among phytoseiid predation rates may be as the result of different environmental factors such as temperature and humidity. According to Skirvin and Fenlon (2003), the adult female of *P. persimilis* ate more *T. urticae* eggs as the increase in temperature from 15 to 25°C, but the number of prey eaten then declines at 30°C.

The age-stage predation rate (c_{xj}) of *P. persimilis* on *T. urticae* eggs is shown in Figure 3 that illustrates the mean number of consumed prey by a predator with age *x* in stage *j*. The non-predatory stages (the eggs and larva) formed two breaks in the predation rate that could be accurately explained only using the age-stage, two-sex life table (Yu *et al*., 2013). The age-specific predation rate (k_x) and age-specific net predation rate (q_x) were calculated using Equations (8) and (9). These parameters were combined for all stages and are plotted in Figure 4. The age-specific predation rate is the mean number of prey consumed per predator of age *x*, while the age-specific net predation rate is the weighted number of consumed prey by a predator of age *x* (Chi and Yang 2003; Yu *et al*., 2013).

The net predation rate (C_0) was 363.54±43.94 *T. urticae* eggs per individual. The transformation rate from prey population to predator offspring (Q_p) was 10.86, indicating that *P. persimilis* requires 10.86 *T. urticae* eggs for the production of each egg.

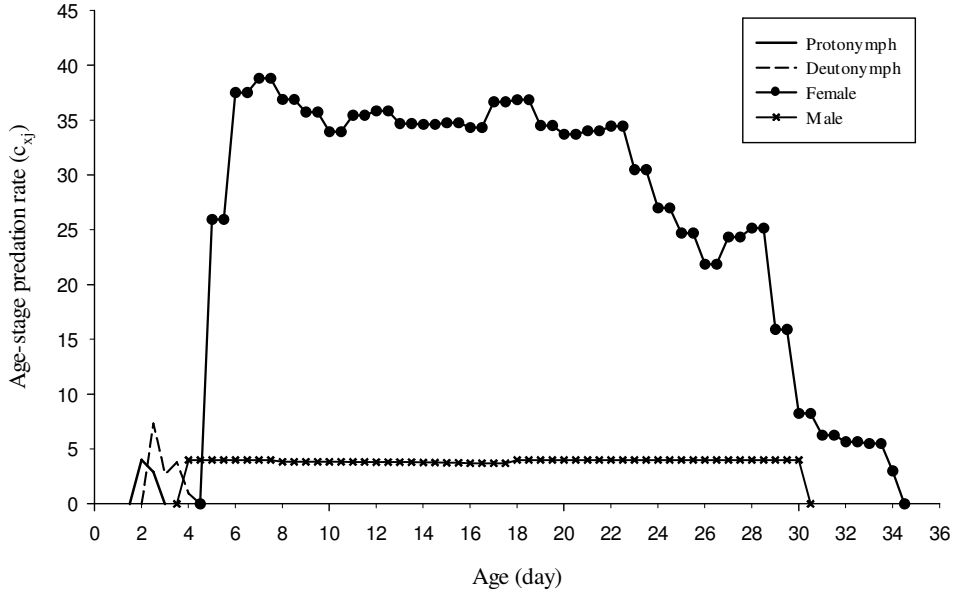

Figure 3. Age-stage predation rate (c_{xj}) of *Phytoseiulus persimilis* on *Tetranychus urticae* eggs at 25±1°C and 75±5% RH.

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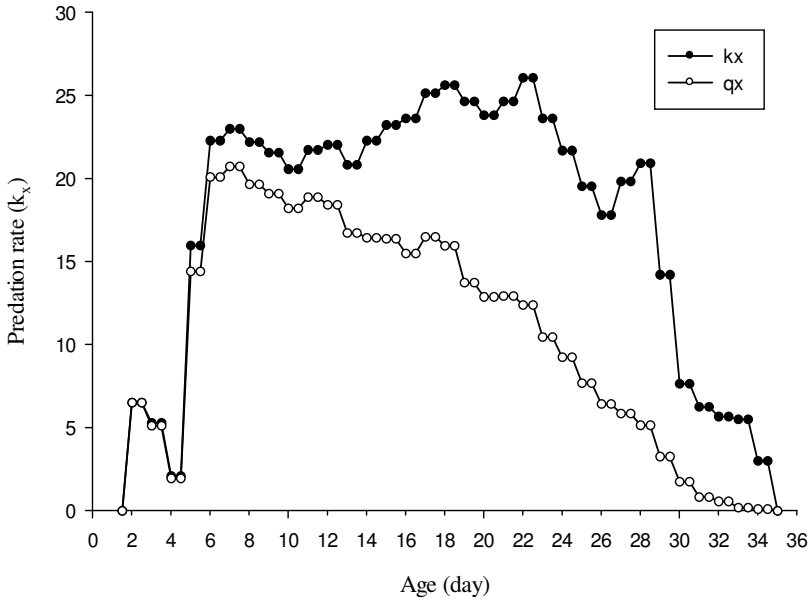

Figure 4. Predation rate (k_x) and net predation rate (q_x) of *Phytoseiulus persimilis* on *Tetranychus urticae* eggs at 25±1°C and 75±5% RH.

Application of Life Table Data

Life table studies are fundamental to not only demography but also to general biology of bio control agents (Chi, 1988). Life table parameters are appropriate indexes of population growth under a defined set of conditions that provide a valuable tool to determine the potential of a bio control agent under different local and seasonal conditions. According to Sabelis (1985c), the capacity of population increase is definitive to the success of phytoseiid predators in biological control of spider mites.

Survival rate, developmental rate and fecundity, are fundamental data that explain the life history and stage differentiation. These data can be used in population planning to describe growth trends, and stage structure of a population in the different periods.

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جدول زندگی و میزان شکارگری *Phytoseiulus persimilis* Athias-Henriot (Acari: Phytoseiidae) با تغذیه از کنه *Tetranychus urticae* Koch (Acari: Tetranychidae) روی رز

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چکیده

در این پژوهش، پارامترهای جدول زندگی و میزان شکارگری مراحل نموی کنه شکارگر *Phytoseiulus persimilis* Athias-Henriot به تفکیک نر و ماده با تغذیه از تخم‌های کنه *Tetranychus urticae* Koch - به عنوان مرحله رشدی مورد ترجیح شکارگر - روی دیسک‌های برگی رز در شرایط آزمایشگاهی (دمای ۱ ± ۲۵ درجه سلسیوس، رطوبت نسبی ۵ ± ۷۵ درصد و دوره نوری ۱۶ ساعت روشنایی و ۸ ساعت تاریکی) مورد بررسی قرار گرفت. بر اساس جدول زندگی دوجنسی ویژه سن-مرحله، پارامترهای جدول زندگی شامل r (نرخ ذاتی افزایش جمعیت)، λ (نرخ متناهی افزایش جمعیت)، R_0 (نرخ خالص تولیدمثل)، GRR (نرخ ناخالص تولیدمثل)و T (مدت یک نسل) برای *P. persimilis* به ترتیب ۰/۰۱۴ ± ۰/۲۹۶بر روز، ۰/۰۱۹ ± ۱/۳۴۵ بر روز، ۴/۹۳ ± ۳۳/۴۸ نتاج، ۶/۲۷ ± ۵۳/۸۷ نتاج و ۰/۲۶ ± ۱۱/۸۳ روز برآورد شد. همچنین بررسی میزان تغذیه مراحل نموی افراد نر و ماده *P. persimilis* از تخم کنه تارتن نشان‌دهنده افزایش میزان شکارگری از مرحله پورگی تا مرحله بلوغ در افراد نر و ماده این شکارگر بود. نتایج آزمون شکارگری نشان داد میزان تغذیه در افراد ماده این شکارگر حدود ۱۱ برابر میزان تغذیه در افراد نر است. میزان خالص شکارگری (C_0) و میزان تبدیل از جمعیت شکار به نتاج شکارگر (Q_p) نیز به ترتیب ۴۳/۹۴ ± ۳۶۳/۵۴ تخم کنه تارتن و ۱۰/۸۶ به دست آمد. نتایج نشان داد که کنه شکارگر *P. persimilis* می‌تواند با تغذیه از کنه تارتن *T. urticae* روی رز چرخه زندگی خود را با موفقیت به پایان رسانده و تولیدمثل کند.

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